first part of the month, as far north as Hongkong (22° N.), but later in the month they arrive farther south, namely, in the Gulf of Tonquin. In November the trend of the hurricane has again become west by north and again they strike the coast of Anam. The origin of this group of hurricanes lies between latitude 6° and 17° N., and they strike the coast between latitude 12° and 23°.

3. The June hurricanes of the third group, having a northwesterly movement, pass between "Breaker Point" (N. 23°, E. 117°) and the Straits of Hainan (N. 20.2°, E. 110.5°), on the south coast of China. Some of them curve backward in the southern portion of Formosa Straits.

4. The July typhoons which, at the beginning, also take a northwest course, can be divided into three classes. Those of the first class move like those of June; those of the second class arrive on the Chinese coast between Amoy (24° N.) and Shanghai (31.3° N.) or curve backward and pass over the Yellow Sea in a north-northeast direction; those of the third class finally recurve opposite Formosa (23.5° N.) and pass over the Sea of Japan.

5. In August the original movements of the cyclones still remain toward the northwest, and in other respects they behave the same as those of July. The September hurricanes move at first toward northwest by west., but in other respects behave like the first and third classes of the July hurricanes.

6. For the hurricanes of the months of the third group (June–September) the zone extends from their place of origin, between latitudes 8° and 20°, to their place of arrival on the Continent of Asia, between the parallels 30° N. and 18° N.

If now, with the assistance of the charts of isobars, we determine the conditions under which the cyclones are formed in the different months and groups of months, we find:

(*a*) The paths of the hurricanes of the Pacific Ocean in the first group start from the region between two areas of high pressure, one of which lies over the continent, the other over the Pacific Ocean. They lead toward the center of low pressure that occupies a portion of Bering Sea. The hurricanes of the China Sea keep within lower latitudes, namely, those which are reached by the limiting isobars of the Asiatic center of high pressure. In proportion as the centers of high pressure flatten out and withdraw during the period from January to March, so these extreme isobars retreat toward the north, and consequently the paths of the hurricanes extend farther north.

(*b*) With reference to the second group, the charts of monthly isobars show that the hurricanes of the Pacific Ocean in April and May move between the extreme isobars of the high pressure areas of the Pacific Ocean and Asia.

(*c*) The paths of the hurricanes of the China Sea keep south of the isobar 760 mm., belonging to the high pressure area of Asia and the low pressure area of Hindostan. In October and November, in proportion as the Asiatic high pressure area develops, these are pushed more and more into lower latitudes; moreover, the development of the area of low pressure in Hindostan is an index to these paths.

(*d*) The hurricanes of the Pacific Ocean, especially in October, pass along the broad zone between the Philippines and Japan, on the one hand, and the isobar of 760 mm. surrounding the high pressure area of the Pacific. In November this zone becomes narrower by reason of the further development of the continental area of high pressure. The hurricanes of the Pacific Ocean belonging to this group also pursue paths toward the depression in the extreme north, which bears north-northeast from Manila.

(*e*) It is characteristic for the months of the third group that from June to September, at least to the middle of the latter month, the center of high pressure withdraws from the coast of Asia, and finally disappears. In connection with this the paths of the hurricanes attain higher latitudes, and those of the Pacific Ocean recurve very near the meridian of 125° east, therefore nearer to the Philippines than in the previous months. A single exception offers in the case of the hurricanes of the second half of September, whose recurving points are from 5° to 8° farther east. All hurricanes in the Pacific Ocean have as their ultimate destination the northern center of low pressure. The paths of the hurricanes of the China Sea trend more toward the north in proportion as the high pressure area of the continent moves northward, and do this, therefore, up to the end of August and the beginning of September; if, however, the low pressure area moves toward the south about the beginning of September, then also the paths of these cyclones must follow it. Some of the July hurricanes after recurving follow paths going very nearly northward; they cross over the Yellow Sea and travel toward a small center of low pressure that has developed in Siberia.

THE INTERNATIONAL CLOUD WORK OF THE WEATHER BUREAU.[1]

By FRANK H. BIGELOW, Professor of Meteorology, U. S. Weather Bureau.

In the month of May, 1896, several national meteorological services began in cooperation to take a series of simultaneous observations on the height and the motion of the ten standard types of clouds which have been defined by the International Committee. The object of this survey of the movements of the atmosphere, continued for at least one year, was to gather material that could be used to determine the action of the higher strata with reference to the formation and the progressive motion of storms. Our observations are generally so exclusively made in the lowest level of the ocean of air that comparatively imperfect information exists regarding the higher currents upon which to found intelligent theories, and it is with the purpose of supplying this deficiency that the series of international observations was undertaken. By the liberal policy of the United States Government, the Weather Bureau was able to do its part of the work. The discussion of the data is now finished for the report which it is expected to issue by the end of the present year. While it is not practicable to give any detailed account of the results, it may be interesting to present a brief synopsis of the scope of the report now being prepared by the writer.

The observations are divided into two classes: (1) The primary, which are made by means of two theodolites placed at the end of a long base line adapted to triangulations in the vertical direction. These give the absolute height, velocity, and direction of motion of individual clouds; between 6,000 and 7,000 of such observations were made at Washington, D. C. (2) The secondary, executed with nephoscopes at 14 stations distributed at nearly equal distances from each other over the districts east of the Rocky Mountains, give the relative velocity and direction of motion, and with the help of the results obtained by the primary system can be translated into absolute values; there were 25,000 to 30,000 of these observations made in the United States.

The discussion of these data has been divided into a number of parts, of which the following may be mentioned in this connection:

1. The distribution of the cirrus, cirro-stratus, cirro-cumulus, alto-cumulus, alto-stratus, strato-cumulus, cumulo-nim-

[1] The important work on which Professor Bigelow has been engaged for several years is now completed and about to be published in the Annual Report for 1898–99. Meantime, our readers will be glad to obtain a comprehensive statement as to the nature of the work; we therefore reprint the accompanying article from the National Geographic Magazine for September, 1899.

bus, nimbus, cumulus, stratus, was so determined that we now know the average height of each type for every month in the year, and the depth of the zone or horizontal belt in which they may severally occur. Thus the upper types are found in layers as much as 6 miles thick, though they form most frequently near the middle of their respective belts; the lower are thinner, and have some peculiar characteristics besides. When we consider that the height and shape of these belts, changing from month to month, indicates some very delicate physical process going on in the aqueous vapor of the atmosphere, it is easy to see that they become the best means for studying the state of the pressure, temperature, and vapor tension—that is, the physics of the air itself.

2. A very important subject has been the determination of the direction and velocities of the horizontal motions of the air in each of the eight principal levels, on all sides of the anti-cyclones and cyclones, high and low areas of pressure, as they move over this country. These movements have been separated into two components, the first belonging to the general or undisturbed motion of the atmosphere, which is about eastward in this latitude, and the second pertaining to the local motions, which are gyratory, and especially concerned with the descending and ascending vortices or storms. This data gives us for the first time definite information regarding storm components, and these enable us to look into the theories much more closely than heretofore.

3. This analysis has been supplemented by a compilation of cloud motions taking place in the cumulus or the cirrus levels, as derived from the Weather Bureau cloud charts collected during the past twenty years, the object of which is to show how the average anticyclone and cyclone are affected by the circulation of the air over different parts of the United States—that is, by the Rocky Mountains, the Lake region, the Gulf of Mexico, and the Atlantic Ocean — the results being exhibited on a series of colored charts.

These practical facts lead to the necessity of definite theoretical studies in order to account for them, and this again to several other lines of research:

1. The first step was to prepare a system of standard constants and formulæ by a comparative study of the papers of several authors, and by the addition of such new demonstrations as seemed desirable, so that the work of many men in their several branches may be read as one consistent meteorological scheme. This standard system represents the outcome of several years' study of the subject. These formulæ include most of the thermodynamic or hydrodynamic conditions likely to arise on a rotating body surrounded by an atmosphere, like the earth.

2. Next, a completely new set of working tables, based upon these formulæ, has been prepared for the barometric reductions from one level to another; for studying with the greatest accuracy the exact conditions of pressure, temperature and vapor tension at the level where a cumulus cloud base forms by the vertical convection, at the place where the hail forms, and at the level where the snow is produced; and finally for computing the dynamic forces and the gradients of motion according to the observed velocities. These tables are permanently useful to meteorology, and that they are needed is seen from the following considerations: (*a*) The Smithsonian tables and the International tables are adapted for the reduction from elevations 2,000 meters or less to the sea level; but in cloud work it is necessary to reduce at will throughout a region up to 15,000 meters in height and with ranges of temperature from $+30°$ to $-60°$ C., which is far beyond the limits of any existing tables. (*b*) The Hertz diagram for adiabatic expansion leaves out the vapor contents of the air in parts of the formulæ, introducing errors of as much as 0.30 inch in pressure. Besides, it is desirable to be able to start with surface conditions and compute upward in exact figures all the elements existing in the cloud, and also the gradients connecting one level with another. (*c*) Since the atmosphere differs very widely from the adiabatic laws, one of our problems is to discuss how large this departure is for all seasons of the year, and from this data we expect to study carefully the laws of solar insolation and terrestrial radiation—that is, the actinometry of the atmosphere—by means of the new and improved material. (*d*) Finally, there are no tables published which are available for computing the dynamic forces indicated by the equations, and these are necessary if meteorology is to be made an exact science.

3. The possession of all this new matter enables us to analyze closely the Ferrel theory of the local cyclone and the German theory of the same, which differ from each other, and to show that they are both only ideal solutions of vortices, and do not conform to the stream lines given by the observations. An attempt has been made to interpret the analytical equations of motion, so that they shall match the observed facts, and this leads to a different idea of the circulation in storms from that commonly taught by meteorologists. The application of the theory to tornadoes is certainly satisfactory, and in the case of hurricanes and cyclones it is on the whole very promising.

FLOODS AND FLOOD PROBLEMS.[1]

By H. C. FRANKENFIELD, Forecast Official, U. S. Weather Bureau, Washington, D. C.

You have discussed, or will discuss, many methods for the improvement of commerce, and the consequent increase of wealth to the country. Of equal importance is the discussion of ways and means looking toward the prevention of loss and damage, and the consequent diminution of wealth, the effect of which would be far-reaching. To this latter branch of your work I have been directed by the Chief of the Weather Bureau to contribute, and I will endeavor to do so by presenting for your consideration a paper on "Floods and Flood Problems of the Mississippi River." About 40 per cent of the entire population of the United States live within the watershed of the Mississippi River, the basin comprising about two-fifths of the total area of the United States; and I therefore submit that any information, however slight, which will contribute to the material welfare of a very considerable portion of this district is worthy of proper consideration.

It may be of interest, by way of preface, to make some brief historical mention of the great floods of the Mississippi system. Nothing except comparatively faint tradition exists regarding the floods preceding those of the present century. In April, 1785, the Mississippi River at St. Louis was said to have reached a stage of 42 feet, or 0.6 feet higher than the well-authenticated stage of June 27, 1844. You all remember the destruction that was wrought by the flood of 1892 in the vicinity of St. Louis. Yet the highest stage reached by the waters in that year was only 36 feet. Conceive, if you can, what would have happened had an additional 6 feet of water been added to the flood volume.

Since the commencement of the present century the notable flood years were 1815, 28, 44, 49, 50, 51, 58, 59, 62, 65, 67, 74, 82, 84, 90, 92, 93, and 97.

Of these the floods previous to that of 1874, while entirely authentic as to occurrence, are not equally so as regards the exact stages of water reached, with the exception of that of 1858, which was the subject of careful and accurate measurement. This lack of exactness was due to the absence of regular

[1] An address delivered at the Tenth Annual Transmississippi Commercial Congress, at Wichita, Kans., May 31, 1899.